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LIQUID HYDROGEN MASS FLOWMETER EVALUATION AND DEVELOPMENT

WYLE LABORATORIES
El Segundo, California

PROGRESS REPORT NO. 1

Contract No. NAS 8-1526
February 10, 1961 through March 31, 1961

Prepared for:

GEORGE C. MARSHALL SPACE FLIGHT CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Redstone Arsenal
Huntsville, Alabama

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ABSTRACT

THIS REPORT ENCOMPASSES THE PROGRESS ACHIEVED UNDER CONTRACT NAS8-1526 DURING THE REPORT PERIOD FEBRUARY 10, 1961 THROUGH MARCH 31, 1961. CONTRACT NAS8-1526 AUTHORIZES WYLE LABORATORIES TO "STUDY, MODIFY OR DEVELOP, TEST AND EVALUATE A HIGH ACCURACY MASS FLOWMETER FOR USE WITH LIQUID HYDROGEN" AND TENTATIVELY CONSISTS OF THE FOLLOWING PROGRAM PHASES:

1) LITERATURE AND INDUSTRY SURVEY

2) ANALYSIS OF "STATE-OF-THE-ART" & SELECTION OF MOST PROMISING DESIGN

3) DESIGN OF CALIBRATION SYSTEM & FABRICATION

4) CHECKOUT OF SYSTEM & PRELIMINARY TESTS

5) ANALYSIS & DESIGN IMPROVEMENTS OF FLOWMETER DESIGN

6) FINAL TESTS OF FLOWMETER

7) FINAL ANALYSIS & DESIGN IMPROVEMENTS

PROGRESS REPORT NO. 1 ENCOMPASSES THE PRELIMINARY RESULTS OF THE LITERATURE AND INDUSTRY SURVEY.

TECHNICAL SUPERVISION OF THE CONTRACT FOR THE MARSHALL SPACE FLIGHT CENTER IS BEING PROVIDED BY MR. A. E. SCHULER, INSTRUMENT DEVELOPMENT SECTION, MEASURING CONTROL AND INSTRUMENTATION BRANCH, TEST DIVISION.

THIS REPORT HAS BEEN
REVIEWED AND APPROVED
FOR WYLE LABORATORIES

L. N. MORTENSON
PROGRAM MANAGER

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SUMMARY

THE RESULTS OF THE PRELIMINARY INDUSTRY SURVEY INDICATE THAT THE FOLLOWING MANUFACTURERS; POTTER-PACIFIC (TWIN TURBINE METER), WAUGH ENGINEERING (AXIAL MOMENTUM-ZERO BLADE ANGLE TURBINE) AND THE DECKER CORPORATION (VIBRATING GYRO) ARE WILLING TO SUBMIT METERS FOR EVALUATION AND POSSESS METERS WHICH, AT LEAST ON A PRELIMINARY BASIS, APPEAR TO MEET THE REQUIREMENTS OF THE PROGRAM.

IN GENERAL, ONLY BRIEF DISCUSSIONS HAVE BEEN HELD WITH THE VARIOUS MANUFACTURERS TO OUTLINE AND DISCUSS THE PHILOSOPHY OF THE PROGRAM. FURTHER TECHNICAL MEETINGS HAVE BEEN SCHEDULED IN WHICH THE DETAILS OF METER OPERATION, PROGRAM PHILOSOPHY, ETC. WILL BE FINALIZED. IT IS INTERESTING TO NOTE THAT AN OPTIMUM MASS FLOWMETER HAS NOT BEEN FOUND FROM THE EXISTING FLOWMETER DESIGNS, I.E., THE POTTER METER IS FELT TO HAVE UNRELIABLE ELECTRONICS AND MAY POSSIBLY BE SUSCEPTIBLE TO SUSTAINED OSCILLATIONS BETWEEN THE TWIN TURBINES: THE WAUGH METER APPEARS TO HAVE A POSSIBLE PROBLEM AREA IN THE USE OF A CONSTANT TORQUE CLUTCH WHICH MAY CHANGE CHARACTERISTICS WITH EITHER TEMPERATURE OR USE; AND THE DECKER METER IS A COMPLEX MECHANICAL DEVICE WHICH WILL BE DIFFICULT TO VACUUM-JACKET OR TO SCALE UP TO LARGE LINE SIZES.

SEVERAL MASS FLOWMETER SYSTEM DESIGNS HAVE BEEN INVESTIGATED BY WYLE WITH UNSUCCESSFUL RESULTS. THE FLOWMETER SYSTEM DESIGNS HAVE EITHER PROVEN UNATTRACTIVE FROM A FEASIBILITY STANDPOINT OR HAVE BORDERED UPON EXISTING PATENTED FLOWMETER PRINCIPLES.

IN PREPARATION FOR THE SCHEDULED TECHNICAL MEETING BETWEEN WYLE AND MARSHALL SPACE FLIGHT CENTER ON APRIL 10 AND 11, 1961, A CALIBRATION SYSTEM BASED UPON A MAXIMUM FLOW RATE OF APPROXIMATELY 50 GPM HAS BEEN DESIGNED AND WILL BE DISCUSSED DURING THE MEETING. IT SHOULD BE NOTED THAT CONTINGENT UPON THE SIZE OF THE FLOWMETERS SELECTED FOR EVALUATION, THE CALIBRATION SYSTEM MAY REQUIRE NOMINAL REDESIGN.

THE PROGRESS OF THE INITIAL PHASE OF THE PROGRAM IS CURRENTLY ON SCHEDULE; HOWEVER, AWAITING THE FINAL RESPONSES OF SEVERAL FLOWMETER MANUFACTURERS IS EXPECTED TO EXTEND THE SCHEDULE FOR SEVERAL WEEKS AS SHOWN ON THE ATTACHED SCHEDULE, APPENDIX A. THE ANALYSIS AND SELECTION PHASE OF THE PROGRAM IS CURRENTLY IN PROGRESS AND IS EXPECTED TO BE COMPLETED ON SCHEDULE. THE DESIGN OF THE CALIBRATION SYSTEM HAS BEEN INITIATED AND

IS PROCEEDING AHEAD OF SCHEDULE. ALTHOUGH A NOMINAL SCHEDULE EXTENSION WILL BE REQUIRED FOR THE SURVEY PHASE OF THE PROGRAM, CONCURRENT PERFORMANCE IN THE VARIOUS PHASES IS EXPECTED TO ELIMINATE THE POSSIBILITY OF ANY SERIOUS SCHEDULE EXTENSIONS.

DISCUSSION

LITERATURE AND INDUSTRY SURVEY

THE SURVEY PHASE OF THE PROGRAM WAS CONDUCTED UTILIZING THE ARMOUR RESEARCH REPORT "STUDY OF MASS FLOWMETERS" ARF PROJECT D173, CONTRACT DA-11-022-ORD-2857 AS THE PRELIMINARY BASIS FOR CONTACTING MANUFACTURERS AND DEVELOPERS OF MASS FLOWMETERS. IN CONDUCTING THE INDUSTRY SURVEY, THE PROGRAM OBJECTIVES AND PHILOSOPHY WERE DISCUSSED WITH EACH MANUFACTURER AND/OR GOVERNMENT AGENCY CONTACTED AS OUTLINED BELOW:

A) PROGRAM REQUIREMENTS FOR FLOWMETER PERFORMANCE.

B) PRINCIPLE OF FLOWMETER OPERATION.

C) POTENTIAL PROBLEM AREAS IN THE USE OF THE FLOWMETER IN A LIQUID HYDROGEN MASS FLOW MEASUREMENT APPLICATION.

D) POSSIBLE WILLINGNESS OF MANUFACTURER TO PARTICIPATE IN THE EVALUATION PHASE OF THE PROGRAM(SUBMITTAL OF METER ON A LOAN BASIS AND SUBSEQUENT ACTIVE PARTICIPATION IN THE DATA ANALYSIS AND POSSIBLE DESIGN IMPROVEMENT PHASES).

E) EXPERIENCE IN EITHER THE FIELD OF MASS FLOW MEASUREMENT OR THE FIELD OF CRYOGENIC FLOW MEASUREMENT.

F) POSSIBLE SOURCES OF ADDITIONAL TECHNICAL INFORMATION.

DURING THE SURVEY PHASE OF THE PROGRAM, 25 FLOWMETER MANUFACTURERS AND/OR GOVERNMENT AGENCIES WERE CONTACTED. WHILE A MAJOR PORTION OF THE SURVEY PHASE OF THE PROGRAM HAS BEEN COMPLETED, IT IS ANTICIPATED THAT ADDITIONAL CONTACTS AND CORRESPONDENCE WITH VARIOUS AGENCIES SHALL CONTINUE FOR AT LEAST THE NEXT FOUR TO SIX WEEK PERIOD. AT LEAST THREE FLOWMETER MANUFACTURERS HAVE DEFINITELY COMMITTED THEMSELVES FOR ACTIVE PARTICIPATION IN THE PROGRAM; POTTER-PACIFIC(TWIN TURBINE), WAUGH ENGINEERING(AXIAL MOMENTUM-ZERO BLADE ANGLE TURBINE) AND THE DECKER CORPORATION(VIBRATING GYRO). THE RESULTS OF THE INDUSTRY SURVEY ARE SUMMARIZED AS FOLLOWS:

1) COMPANY: POTTER AERONAUTICAL CORPORATION

TYPE OF INSTRUMENT: TWIN TURBINE METER

MFG'S. RESPONSE: INTERESTED AND WILLING TO SUBMIT METER ON LOAN BASIS FOR EVALUATION AND ACTIVELY PARTICIPATE IN THE PROGRAM.

COMMENTS: PRELIMINARY DISCUSSIONS HAVE BEEN HELD WITH THE POTTER COMPANY. POTTER IS WILLING TO SUBMIT A METER ON A LOAN BASIS AND IS ANXIOUS TO PARTICIPATE IN THE PROGRAM. A TECHNICAL MEETING HAS BEEN SCHEDULED APRIL 3RD AT THE POTTER AERONAUTICAL, UNION, NEW JERSEY FACILITY IN WHICH THE DETAILS OF THE METER OPERATION AND THE EXTENT OF POTTER'S PARTICIPATION IN THE PROGRAM WILL BE DISCUSSED.

RECOMMENDATION: BASED UPON A PRELIMINARY ANALYSIS OF THE TWIN TURBINE METER, POTTER'S WILLINGNESS TO PARTICIPATE IN THE PROGRAM, AND EXTENSIVE EXPERIENCE IN CRYOGENIC FLOW MEASUREMENT, IT IS RECOMMENDED THAT THE POTTER TWIN TURBINE FLOWMETER BE CONSIDERED FOR THE EVALUATION AND DEVELOPMENT PROGRAM.

2) COMPANY: THE DECKER CORPORATION

TYPE OF INSTRUMENT: VIBRATING GYRO

MFG'S. RESPONSE: INTERESTED AND WILLING TO SUBMIT METER ON LOAN BASIS FOR EVALUATION AND ACTIVELY PARTICIPATE IN THE PROGRAM.

COMMENTS: SEVERAL PRELIMINARY DISCUSSIONS HAVE BEEN HELD WITH THE DECKER CORPORATION AND AVAILABLE TECHNICAL INFORMATION HAS BEEN FORWARDED TO WYLE. A TECHNICAL MEETING HAS BEEN SCHEDULED APRIL 4TH AT THE DECKER CORPORATION BALA-CYNWYD FACILITY. IT IS THE INTENTION OF THIS MEETING TO FINALIZE THE EXTENT OF PARTICIPATION IN THE PROGRAM BY THE DECKER CORPORATION AND TO FINALIZE SUCH QUESTIONS AS AVAILABILITY AND SIZE OF METERS FOR EVALUATION, POSSIBLE METHODS OF VACUUM-JACKETING THE METER, ETC.

RECOMMENDATIONS: BASED UPON FAVORABLE PERFORMANCE OF THE DECKER METER DURING THE EVALUATION TESTING CONDUCTED BY ARMOUR RESEARCH FOUNDATION (REF. NO. 1) AND THE WILLINGNESS OF THE MANUFACTURER TO PARTICIPATE IN THE PROGRAM, IT IS RECOMMENDED THAT THE DECKER GYROSCOPIC MASS FLOWMETER BE CONSIDERED FOR THE EVALUATION AND DEVELOPMENT PROGRAM.

3) COMPANY: WAUGH ENGINEERING

TYPE OF INSTRUMENT: AXIAL MOMENTUM-ZERO BLADE ANGLE TURBINE.

MFG'S. RESPONSE: INTERESTED AND WILLING TO SUBMIT A METER ON LOAN BASIS FOR EVALUATION AND ACTIVELY PARTICIPATE IN THE PROGRAM.

COMMENTS: WAUGH ENGINEERING IS CURRENTLY DEVELOPING A 5 INCH, 3 TO 15 POUNDS PER SECOND LIQUID HYDROGEN MASS FLOWMETER UNDER SUBCONTRACT TO THE AEROJET-GENERAL CORPORATION, AZUSA, CALIFORNIA, WHO, IN TURN, IS CONDUCTING THE DEVELOPMENT UNDER CONTRACT AF33(616)-6811. PRELIMINARY DISCUSSIONS HAVE INDICATED THAT WAUGH ENGINEERING MAY BE WILLING TO MANUFACTURE A MASS FLOWMETER OF AN APPROXIMATE 2 INCH LINE SIZE FOR EVALUATION PURPOSES. TECHNICAL INFORMATION DETAILING THE DEVELOPMENT OF THE MASS FLOWMETER HAS NOT BEEN AVAILABLE SINCE THIS WORK IS BEING CONDUCTED UNDER A CURRENT CONTRACT. SUBSEQUENT DISCUSSIONS WITH WAUGH, AEROJET, AND EDWARDS AIR FORCE BASE PERSONNEL HAVE INDICATED THAT COMPLETE TECHNICAL INFORMATION PERTINENT TO THE FLOWMETER DESIGN AND TESTING MAY BE OBTAINED IN THE QUARTERLY PROGRESS REPORTS SUBMITTED BY AEROJET-GENERAL CORPORATION TO EDWARDS AIR FORCE BASE. IT IS REQUESTED THAT MARSHALL SPACE FLIGHT CENTER FORMALLY REQUEST MR. D. LIMBACKER OF EDWARDS AIR FORCE BASE TO PLACE WYLE LABORATORIES ON THE DISTRIBUTION LIST FOR QUARTERLY PROGRESS REPORTS GENERATED UNDER THE SUBJECT CONTRACT AND ENTITLED "HYDROGEN MASS FLOWMETER DEVELOPMENT."

RECOMMENDATION: BASED UPON A PRELIMINARY ANALYSIS OF THE WAUGH ENGINEERING MASS FLOWMETER AND THE WILLINGNESS OF THE MANUFACTURER TO PARTICIPATE IN THE EVALUATION PROGRAM, IT IS RECOMMENDED THAT THE WAUGH ENGINEERING AXIAL MOMENTUM MASS FLOWMETER BE CONSIDERED FOR THE EVALUATION AND DEVELOPMENT PROGRAM.

4) COMPANY: FISCHER & PORTER COMPANY

TYPE OF INSTRUMENT: VOLUMETRIC TURBINE METER WITH DENSITY COMPENSATION

MFG'S. RESPONSE: INTERESTED IN PROGRAM BUT NOT PRESENTLY MANUFACTURING A MASS FLOWMETER.

COMMENTS: FISCHER & PORTER HAS IN THE PAST MARKETED A MASS FLOWMETER CONSISTING OF THEIR STANDARD VOLUMETRIC METER WITH DENSITY COMPENSATION BEING DERIVED FROM THE

DRAG FORCES EXERTED ON A DISC IMMERSED IN THE FLOW STREAM. SEVERAL DISCUSSIONS HAVE BEEN HELD WITH FISCHER & PORTER IN WHICH IT WAS LEARNED THAT THE MASS METER DESCRIBED WAS WITHDRAWN FROM FURTHER PRODUCTION DUE TO PROBLEMS ENCOUNTERED IN MASS PRODUCING THIS TYPE OF FLOWMETER WHILE MAINTAINING A SYSTEM ACCURACY GREATER THAN ± 0.5%. FISCHER & PORTER IS STILL IN POSSESSION OF SEVERAL OF THE DENSITY COMPENSATED MASS FLOWMETERS. A TECHNICAL MEETING HAS BEEN SCHEDULED ON APRIL 5, 1961, AT THE FISCHER & PORTER, HATBORO, PENNSYLVANIA FACILITY. DURING THIS MEETING THE POSSIBILITY OF OBTAINING ONE OF THE DENSITY COMPENSATED VOLUMETRIC MASS METERS FOR EVALUATION WILL BE DISCUSSED. IN ADDITION, THE RELATIVE MERITS AND ADVANTAGES OF THIS TYPE OF METERING SYSTEM WILL BE DISCUSSED.

RECOMMENDATIONS: IT IS RECOMMENDED THAT A DECISION ON THE POSSIBLE EVALUATION OF THE FISCHER & PORTER MASS FLOWMETER SYSTEM BE DEFERRED UNTIL AFTER THE TECHNICAL MEETING TO BE HELD APRIL 4TH.

5) COMPANY: STANDARD CONTROLS, INC.

TYPE OF INSTRUMENT: DRAG ON REED (STRAIN GAGE)

MFG'S. RESPONSE: INTERESTED IN PROGRAM AND WILLING TO SUBMIT METER FOR EVALUATION ON A LOAN BASIS.

COMMENTS: THE PRINCIPLE OF METER OPERATION IS ONE IN WHICH THE BENDING MOMENT ON A REED IN THE FLUID STREAM IS MEASURED WITH A STRAIN GAGE. THE BENDING MOMENT WOULD NORMALLY BE A FUNCTION OF THE MASS FLOW MOMENTUM ($C_D A \rho V^2/2g$); HOWEVER, IN THIS TYPE OF APPLICATION, THE REED IS FABRICATED FROM AN EXTREMELY FLEXIBLE MATERIAL AND IS INTENDED TO DEFORM UNDER FLOW CONDITIONS SUCH THAT THE CHANGE IN DRAG COEFFICIENT AND FRONTAL AREA WILL COMPENSATE THE BASIC MASS MOMENTUM FUNCTION SO THAT A DIRECT MASS FLOW READING IS OBTAINED. AT THE PRESENT TIME, VERY LITTLE CALIBRATION DATA IS AVAILABLE; HOWEVER, THE MANUFACTURER FEELS THAT THE METER SHOULD COMPENSATE FOR DENSITY CHANGES OF APPROXIMATELY 5% TO 10%.

RECOMMENDATIONS: DUE TO THE LIMITED EXPERIENCE OF THE MANUFACTURER, AND POTENTIAL PROBLEM AREAS ATTENDANT WITH THE DEVELOPMENT OF CRYOGENIC STRAIN GAGE INSTALLATIONS AND THE VARIABLE AREA-DRAG COEFFICIENT COMPENSATION PRINCIPLE, IT IS RECOMMENDED THAT THE STANDARD CONTROLS FLOWMETER BE OMITTED FROM CONSIDERATION IN EVALUATION AND DEVELOPMENT PROGRAM.

6) COMPANY: CONSOLIDATED ELECTRODYNAMICS CORPORATION

TYPE OF INSTRUMENT: HEAT TRANSFER (LAUB PRINCIPLE)

MFG'S. RESPONSE: INTERESTED IN PROGRAM BUT METER NEEDS EXTENSIVE DEVELOPMENT.

COMMENTS: THE METER IS STILL IN THE DEVELOPMENT PHASE, I.E., TESTING TO DATE HAS BEEN CONCERNED WITH ESTABLISHING THE BASIC PARAMETERS RELATING TO ACCURACY, REPEATABILITY, LINEARITY, ETC. CONSOLIDATED ELECTRODYNAMICS CORPORATION WOULD NOT BE WILLING TO PROVIDE A METER ON A LOAN BASIS DUE TO THE EXTENSIVE EXPENDITURE OF COMPANY FUNDS WHICH WOULD BE REQUIRED BEFORE TESTING COULD BE CONDUCTED.

RECOMMENDATIONS: DUE TO THE EXTENSIVE DEVELOPMENT REQUIRED, IT IS RECOMMENDED THAT THE CEC HEAT TRANSFER MASS FLOWMETER BE OMITTED FROM CONSIDERATION IN THE EVALUATION AND DEVELOPMENT PROGRAM.

7) COMPANY: FLOW MEASUREMENT CORPORATION

TYPE OF INSTRUMENT: HEAT TRANSFER (LAUB PRINCIPLE)

MFG'S RESPONSE: INTERESTED IN PROGRAM; HOWEVER, THE PRESENT METER IS NOT DIRECTLY APPLICABLE TO LIQUID HYDROGEN MASS FLOW MEASUREMENT.

COMMENTS: THE FLOW MEASUREMENT CORPORATION METER IS NOT A TRUE MASS METER IN THE SENSE THAT IT IS POSSIBLE TO CALIBRATE THE METER WITH A GIVEN FLUID IN MASS UNITS AND USE THE METER WITH OTHER FLUIDS. THE METER IS, HOWEVER, ATTRACTIVE FROM THE STANDPOINT OF NO MOVING PARTS AND RELATIVELY SIMPLE CONSTRUCTION. THE PRESENT ACCURACY OF THE INSTRUMENT IS ONE TO TWO PERCENT. TECHNICAL INFORMATION HAS BEEN FORWARDED TO WYLE, AND A TENTATIVE MEETING HAS BEEN SCHEDULED FOR APRIL 7TH AT THE FLOW MEASUREMENT CORPORATION FACILITY IN KENSINGTON, MARYLAND. DURING THIS MEETING, THE POSSIBLE DEVELOPMENT OF THE METER FOR USE IN LIQUID HYDROGEN SYSTEMS WILL BE MORE FULLY DISCUSSED.

RECOMMENDATIONS: IT IS RECOMMENDED THAT ANY ACTION PERTAINING TO THE POSSIBLE EVALUATION AND DEVELOPMENT OF THE FLOW MEASUREMENT CORPORATION METER BE DEFERRED UNTIL AFTER THE TECHNICAL SESSION BETWEEN WYLE LABORATORIES AND THE FLOW MEASUREMENT CORPORATION ON APRIL 7, 1961.

8) COMPANY: PIONEER CENTRAL DIVISION
BENDIX CORPORATION

TYPE OF INSTRUMENT: CORIOLIS

MFG'S RESPONSE: NOT INTERESTED IN CONTRIBUTING OR PARTICIPATING IN THE EVALUATION AND DEVELOPMENT PROGRAM AT THIS TIME.

COMMENTS: BENDIX IS IN THE PROCESS OF DELIVERING A 600,000 POUNDS PER HOUR LIQUID OXYGEN METER TO EDWARDS AIR FORCE BASE FOR A FACILITIES INSTALLATION. EXTENSIVE MODIFICATION OF THEIR PRESENT LOX MASS FLOWMETER DESIGN IS REQUIRED BEFORE THE METER MAY BE USED IN A LIQUID HYDROGEN FLOW SYSTEM. BENDIX IS CURRENTLY UNDERTAKING THIS MODIFICATION AND IT IS EXPECTED TO REQUIRE AT LEAST SIX MONTHS. BENDIX WILL ATTEMPT TO FORWARD AVAILABLE TECHNICAL INFORMATION WHICH WILL BE OF USE IN THE PREPARATION OF THE SURVEY PORTION OF THE FINAL TECHNICAL REPORT.

RECOMMENDATIONS: IT IS RECOMMENDED THAT THE BENDIX CORPORATION FLOWMETER BE OMITTED FROM CONSIDERATION IN THE EVALUATION AND DEVELOPMENT PROGRAM.

9) COMPANY: DANIEL ORIFICE FITTING COMPANY

TYPE OF INSTRUMENT: "TRUE VELOCITY" WITH DENSITY COMPENSATION

MFG'S RESPONSE: INTERESTED.

COMMENTS: NO TECHNICAL INFORMATION PERTAINING TO THE METER DESIGN OR OPERATION IS PRESENTLY AVAILABLE SINCE THE METER IS STILL IN THE DEVELOPMENT PHASE AND IS FELT TO BE PROPRIETARY. SHOULD DANIEL ORIFICE DECIDE TO PARTICIPATE IN THE PROGRAM, THEY WILL FORWARD ADDITIONAL TECHNICAL INFORMATION AND DESCRIPTION OF THEIR METER.

RECOMMENDATION: IT IS RECOMMENDED THAT ANY ACTION PERTAINING TO THE POSSIBLE EVALUATION AND DEVELOPMENT OF THE DANIEL ORIFICE FITTING COMPANY MASS FLOWMETER BE DEFERRED UNTIL SUFFICIENT TECHNICAL INFORMATION IS OBTAINED TO PROPERLY EVALUATE THE METER.

10) COMPANY: ROCKETDYNE

TYPE OF INSTRUMENT: UNKNOWN.

MFG'S. RESPONSE: NOT INTERESTED IN CONTRIBUTING OR PARTICIPATING IN THE EVALUATION AND DEVELOPMENT PROGRAM AT THIS TIME.

COMMENTS: ROCKETDYNE IS CURRENTLY IN THE DEVELOPMENT PHASE OF A METER FOR USE IN THE J-2 ENGINE SYSTEM OF SATURN. A METER WOULD NOT BE AVAILABLE FOR TESTING FOR AT LEAST SEVERAL MONTHS.

RECOMMENDATION: NONE.

11) COMPANY: QUANTUM DYNAMICS

TYPE OF INSTRUMENT: TWIN TURBINE VOLUMETRIC METER WITH DENSITY COMPENSATION.

MFG'S. RESPONSE: NOT INTERESTED IN CONTRIBUTING TO THE EVALUATION AND DEVELOPMENT PROGRAM AT THIS TIME.

COMMENTS: QUANTUM DYNAMICS IS APPREHENSIVE ABOUT RELEASING DETAILED INFORMATION DESCRIBING THE TWIN TURBINE VOLUMETRIC METER OR THE METHOD OF DENSITY COMPENSATION DUE TO PROPRIETARY CONFLICTS.

RECOMMENDATIONS: IT IS RECOMMENDED THAT THE QUANTUM DENSITY FLOWMETER BE OMITTED FROM CONSIDERATION IN THE EVALUATION AND DEVELOPMENT PROGRAM.

12) COMPANY: LINDE COMPANY

TYPE OF INSTRUMENT: NONE.

MFG'S. RESPONSE: INTERESTED IN PROGRAM.

COMMENTS: LINDE'S CURRENT INTEREST IN THE FIELD OF LIQUID HYDROGEN MASS FLOW MEASUREMENT IS IN THE DELIVERY OF LIQUID HYDROGEN. LINDE IS PRESENTLY DETERMINING THE QUANTITY OF LIQUID HYDROGEN SOLD BY WEIGHING THE DELIVERY TRUCK BEFORE AND AFTER DELIVERY.

RECOMMENDATIONS: NONE.

13) COMPANY: NATIONAL BUREAU OF STANDARDS
CRYOGENIC ENGINEERING LABORATORIES

TYPE OF INSTRUMENT: NONE.

MFG'S. RESPONSE: INTERESTED IN PROGRAM.

COMMENTS: NBS IS CURRENTLY CONDUCTING SEVERAL RESEARCH AND DEVELOPMENT PROGRAMS (CRYOGENIC INSTRUMENTATION) FOR THE LEWIS RESEARCH CENTER. NBS HAS BEEN MOST HELPFUL AND IS EAGER TO COORDINATE THE EFFORTS OF THE NBS AND WYLE PROGRAMS BEING CONDUCTED FOR NASA. WYLE HAS BEEN PLACED ON THE DISTRIBUTION LIST AND WILL RECEIVE COPIES OF THE NBS QUARTERLY PROGRESS REPORTS ISSUED FOR THE LEWIS RESEARCH CENTER PROGRAM.

RECOMMENDATIONS: NONE.

14) COMPANY: GENERAL ELECTRIC

TYPE OF INSTRUMENT: AXIAL MOMENTUM

MFG'S. RESPONSE: NOT INTERESTED IN PARTICIPATION IN THE EVALUATION AND DEVELOPMENT PROGRAM AT THIS TIME.

COMMENTS: WHILE THE GENERAL ELECTRIC MASS FLOWMETER HAS ACHIEVED A GREAT DEAL OF USE AND EXPERIENCE IN THE FIELD OF MASS FLOW MEASUREMENT, THIS EXPERIENCE HAS BEEN EXCLUSIVELY IN NON-CRYOGENIC APPLICATIONS. THE EXISTING METER WOULD REQUIRE EXTENSIVE MODIFICATION TO THE DRIVE MECHANISM AND READOUT EQUIPMENT, PRIOR TO USE IN A LIQUID HYDROGEN SYSTEM. GENERAL ELECTRIC HAS TENTATIVELY EXPRESSED A DISINTEREST IN THE PROGRAM DUE TO THE EXTENSIVE MODIFICATIONS REQUIRED TO ADAPT THEIR METER FOR CRYOGENIC APPLICATIONS. HOWEVER, A FORMAL RESPONSE TO THE ORIGINAL INQUIRY HAS NOT, AS YET, BEEN RECEIVED.

RECOMMENDATIONS: NONE.

15) COMPANY: AEROJET-GENERAL CORPORATION, AZUSA

TYPE OF INSTRUMENT: REFERENCE WAUGH ENGINEERING.

COMMENTS: AEROJET WAS CONTACTED WITH RESPECT TO INTERCHANGE OF TECHNICAL INFORMATION RELATING TO THEIR MASS FLOWMETER DEVELOPMENT PROGRAM WITH WADD. FUTURE TECHNICAL CONTACTS WITH AEROJET WILL BE MAINTAINED IN ORDER THAT TECHNICAL REPORTS DESCRIBING THE OPERATION OF THE WAUGH FLOWMETER MAY BE EVALUATED.

RECOMMENDATIONS: NONE

16) COMPANY: AVIEN

TYPE OF INSTRUMENT: AXIAL MOMENTUM

MFG'S. RESPONSE: INTERESTED IN PROGRAM.

COMMENTS: ALTHOUGH AVIEN WOULD BE INTERESTED IN PARTICIPATING IN THE EVALUATION AND DEVELOPMENT PROGRAM, THEIR PRESENT AXIAL MOMENTUM METER WOULD REQUIRE EXTENSIVE DEVELOPMENT PRIOR TO USE IN A LIQUID HYDROGEN SYSTEM. AT PRESENT, LITTLE TECHNICAL INFORMATION IS AVAILABLE DESCRIBING THE DESIGN OR OPERATION OF THE AVIEN AXIAL MOMENTUM METER.

RECOMMENDATIONS: NONE.

17) COMPANY: MAXSON CORPORATION

TYPE OF INSTRUMENT: ACOUSTIC

MFG'S RESPONSE: NOT INTERESTED.

COMMENTS: NONE

RECOMMENDATIONS: NONE.

18) COMPANY: GULTON INDUSTRIES

TYPE OF INSTRUMENT: ACOUSTIC

MFG'S. RESPONSE: INTERESTED IN PROGRAM.

COMMENTS: GULTON IS CURRENTLY MANUFACTURING A NON-CRYOGENIC MASS FLOWMETER OF APPROXIMATE 2 INCH LINE SIZE. GULTON IS INTERESTED IN THE PROGRAM BUT WOULD NOT BE WILLING TO SUBMIT A FLOWMETER FOR EVALUATION ON A LOAN BASIS DUE TO THE EXTENSIVE MODIFICATION REQUIRED TO ADAPT THE METER FOR CRYOGENIC APPLICATIONS.

RECOMMENDATIONS: IT IS RECOMMENDED THAT THE GULTON FLOWMETER BE OMITTED FROM CONSIDERATION IN THE EVALUATION AND DEVELOPMENT PROGRAM.

19) COMPANY: REVERE CORPORATION OF AMERICA

TYPE OF INSTRUMENT: ADJUSTABLE VANE

MFG'S. RESPONSE: NOT INTERESTED.

COMMENTS: REVERE CORPORATION DOES NOT CURRENTLY MANUFACTURE A METER CAPABLE OF SATISFYING THE PROGRAM REQUIREMENTS.

20) COMPANY: ACOUSTICA

TYPE OF INSTRUMENT: ACOUSTIC

MFG'S. RESPONSE: NOT INTERESTED.

COMMENTS: NONE.

RECOMMENDATIONS: NONE.

21) COMPANY: AIRESEARCH MANUFACTURING CORPORATION

TYPE OF INSTRUMENT: NONE.

MFG'S. RESPONSE: INTERESTED IN PROGRAM.

COMMENTS: AIRESEARCH HAS CONDUCTED PRELIMINARY DEVELOPMENT WORK ON A MASS FLOWMETER, BASED UPON PRINCIPLES OF MAGNETOHYDRODYNAMICS. THIS DEVELOPMENT HAS SUBSEQUENTLY BEEN CANCELLED, AND AIRESEARCH IS NO LONGER DEVELOPING A MASS FLOWMETER.

RECOMMENDATIONS: NONE.

22) COMPANY: COX INSTRUMENT DIVISION
GEORGE L. NANKERVIS COMPANY

TYPE OF INSTRUMENT: UNKNOWN.

MFG'S. RESPONSE: INTERESTED IN PROGRAM.

COMMENTS: COX IS CURRENTLY DEVELOPING A MASS METER UTILIZING A TRIPLE TURBINE IN WHICH A SINGLE TURBINE PROVIDES VOLUMETRIC DATA, AND THE REMAINING TWIN TURBINE ASSEMBLY PROVIDES DENSITY DATA. THE RESULTANT SIGNALS ARE COMBINED TO PRODUCE A MASS READING. COX IS CURRENTLY CONSIDERING POSSIBLE PARTICIPATION IN THE EVALUATION AND DEVELOPMENT PROGRAM. AT THE PRESENT TIME, NO TECHNICAL INFORMATION IS AVAILABLE DESCRIBING THE OPERATION OF THE METER.

RECOMMENDATIONS: IT IS RECOMMENDED THAT ANY ACTION PERTAINING TO THE POSSIBLE EVALUATION AND DEVELOPMENT OF THE COX MASS FLOWMETER BE DEFERRED UNTIL SUFFICIENT TECHNICAL INFORMATION IS OBTAINED TO PROPERLY EVALUATE THE METER.

23) COMPANY: DOUGLAS AIRCRAFT COMPANY

TYPE OF INSTRUMENT: UNKNOWN

MFG'S. RESPONSE: NOT INTERESTED IN PARTICIPATION IN THE EVALUATION AND DEVELOPMENT PROGRAM AT THIS TIME.

COMMENTS: DOUGLAS IS CURRENTLY CONDUCTING LIMITED TESTS WITH MODIFIED TURBINE METERS TO DETERMINE POSSIBLE USE WITH LIQUID HYDROGEN.

RECOMMENDATIONS: NONE.

24) COMPANY: NASA (LEWIS RESEARCH CENTER)

TYPE OF INSTRUMENT: NONE.

MFG'S. RESPONSE: INTERESTED IN PROGRAM.

COMMENTS: THE LEWIS RESEARCH CENTER WAS CONTACTED WITH RESPECT TO COORDINATION OF THE WYLE PROGRAM WITH THE CURRENT NBS CRYOGENIC INSTRUMENTATION PROGRAM. A VERY FAVORABLE RESPONSE WAS OBTAINED AND TECHNICAL COORDINATION WILL BE MAINTAINED THROUGHOUT THE REMAINDER OF THE CONTRACT.

RECOMMENDATIONS: NONE.

25) COMPANY: SPACE INSTRUMENTS CORPORATION

TYPE OF INSTRUMENT: UNKNOWN.

MFG'S. RESPONSE: A FORMAL RESPONSE HAS NOT BEEN RECEIVED.

COMMENTS: A QUESTIONNAIRE TYPE LETTER WAS FORWARDED TO THE SPACE INSTRUMENTS CORPORATION ON MARCH 22, 1961, AND, AS YET, SPACE INSTRUMENTS CORPORATION HAS NOT HAD SUFFICIENT TIME TO PROPERLY RESPOND.

RECOMMENDATIONS: NONE.

PRELIMINARY DESIGN OF CALIBRATION SYSTEM

IN PREPARATION FOR THE SCHEDULED TECHNICAL MEETING BETWEEN WYLE AND MARSHALL SPACE FLIGHT CENTER ON APRIL 10 AND 11, 1961, A CALIBRATION SYSTEM BASED UPON A MAXIMUM FLOW RATE OF APPROXIMATELY 50 GPM HAS BEEN TENTATIVELY DESIGNED. THE SYSTEM DESIGN IS BASED UPON DYNAMIC WEIGHING OF THE CONTENTS OF A 60 GALLON LIQUID HYDROGEN STORAGE VESSEL. THE DESIGN INCORPORATES BOTH THE 60 GALLON LIQUID HYDROGEN TEST VESSEL AND THE HELIUM PRESSURIZATION SOURCE MOUNTED ON A MECHANICAL SCALE SYSTEM. THE TEST VESSEL DESIGN INCORPORATES THE USE OF A LIGHTWEIGHT INTERIOR STAINLESS STEEL TANK, 6 INCHES OF FOAM INSULATION, AND A LIGHTWEIGHT OUTER TANK. THE FLEXIBLE HOSE LEADING FROM THE SCALE SYSTEM, AND THE ASSOCIATED TRANSFER PIPING, HAVE BEEN DESIGNED AS DOUBLE-WALL COPPER LINES WITH ALUMINUM FOIL/FIBERGLASS, HIGH-VACUUM INSULATION.

IT SHOULD BE NOTED THAT CONTINGENT UPON THE SIZE OF FLOWMETERS SELECTED FOR EVALUATION, THE CALIBRATION SYSTEM MAY REQUIRE NOMINAL REDESIGN. SUBSEQUENT REPORTS WILL INCLUDE COMPLETE DESIGN DETAILS AND SCHEMATIC DIAGRAMS OF THE CALIBRATION SYSTEM.

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APPENDIX A

CONTRACT No. NAS8-1526
APRIL 3, 1961

PROGRAM STATUS

TASK	FEB	MAR	APR	MAY	JUNE	1961 JULY	AUG	SEPT	OCT	NOV	DEC	1962 JAN
1. LITERATURE & INDUSTRY SURVEY	XXXX ****	XXXX ****	////									
2. ANALYSIS OF "STATE-OF-THE-ART" & SELECTION OF MOST PROMISING DESIGN		XXXX ****	XXXX									
3. DESIGN OF CALIBRATION SYSTEM & FABRICATION		**	XXXX	XX								
4. CHECKOUT OF SYSTEM & PRELIMINARY TESTS				XX	XXXX	XXXX						
5. ANALYSIS & DESIGN IMPROVEMENTS OF FLOWMETER DESIGN						XXXX	XXXX					
6. FINAL TESTS OF FLOWMETER								XXXX	XXXX	XXXX		
7. FINAL ANALYSIS & DESIGN IMPROVEMENT										XXXX		
8. REPORT (FINAL)											XXXX	XXXX
9. REPORT (MONTHLY)	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX

XXXX - ORIGINAL SCHEDULE
**** - PROGRAM PROGRESS
//// - SCHEDULE EXTENSION